SUMMARY OF SESSION D: SIMULATIONS OF ELECTRON CLOUD BUILD UP I

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Abstract

This report is a brief summary of the session D of the workshop ECLOUD04 about electron cloud build up simulations (Part I). In this session the status of some of the existing codes for the build up simulations has been reported and updates on the progress towards new powerful 3D and self-consistent codes have been presented. Simulations specifically applied to damping rings for linear colliders (CLIC, TESLA, NLC), DAΦNE, PETRA III, ISIS, ESS have been also discussed.

LIST OF THE CONTRIBUTIONS

The talks presented in session D, and relative speakers, were:

- *Electron cloud build up simulations with ECLOUD*, Daniel Schulte (CERN)
- *Numerical and computational methods in electron cloud simulations: present and future*, Andreas Adelmann (PSI)
- *Overview of the electron cloud studies for the future linear colliders*, Mauro Pivi (SLAC)
- *Prediction of electron cloud effects in synchrotron light source PETRA III*, Rainer Wanzenberg (DESY)
- *E-cloud simulations for DAΦNE*, Cristina Vaccarezza (LNF-INFN)
- *E-cloud effects in the TESLA and CLIC positron damping rings*, Rainer Wanzenberg (DESY)
- *Status report on the merging of the electron cloud code POSINST with the 3-D accelerator PIC code WARP*, Jean Luc Vay (LBNL)
- *Simulation of electron cloud build up in the ISIS proton synchrotron and related machines*, Giulia Bellodi (RAL)
- *Effect of the beam instability on the density of the cloud/Secondary yield in the presence of the beam*, Sam Heifets (SLAC)

SUMMARIES

Updates on ECLOUD

D. Schulte presented an overview on the updates of the ECLOUD code and a few examples of recent applications and benchmarks with experimental data from the SPS.

A crash program of debugging and the replacement of some old routines with quicker ones for space charge calculation and for particle tracking in magnetic fields, strongly increased our level of confidence in the ECLOUD code predictions and made it up to 80–200 times faster for the simulations of electron cloud build up in dipole fields. A number of key issues were addressed by D. Schulte in his presentation: importance of the correct boundary conditions both in the geometry of the problem and in the electric field calculations, influence of elastic reflection of electrons at low energy incidence, scrubbing, proper modeling of the strip detector, benchmark of ECLOUD with the measured heat load from the WAMPAC experiment (V. Baglin) and with the signal from the strip detector.

Different boundary conditions can be handled by the ECLOUD code. Round, elliptical and rectangular geomotries have been already available for the last few years. The LHC-shaped beam pipe was previously included as option only insofar the trajectory of the electrons hitting the beam pipe and encountering then the correct boundary was being evaluated. In the calculation of the electric field, the LHC-shaped beam pipe would be replaced by the the largest inscribed ellipse. The recent introduction of the option of LHC-shaped beam pipe both for real boundaries and fields shows that there might be a significant difference in the build up dynamics in drift space. The difference concerns the rise time of the cloud rather than its saturation value, which does not appear to be much affected by the refinement of the model.

For sake of better benchmarking with experimental data, a realistic modeling of the strip detector was introduced, which accounts for the presence of the measuring holes and of the bias voltage in the detector. The simulated electron flux, which matches the observed position of the two stripes in a dipole field with quite high accuracy, fits more closely the observed flux at all horizontal locations along the chamber.

Scrubbing was been to the ECLOUD code by recording the electron dose run by run and changing (even locally) the SEY accroding to a predefined decaying law inferred from laboratory measurements.

Benchmarking with experiments does not concern only the strip detector. The energy spectrum of the electrons hitting the beam pipe has been successfully ccompared to the measured one (at least for energies higher than a few tens of eV) and also the heat load measured in WAMPAC 1 seems to be satisfactorily reproduced by the ECLOUD code.

Towards 3-D self-consistent beam-cloud simulations: present and future.

A. Adelmann first summarized the existing codes in terms of structure and performances, and then reported on the status of the PARSEC code (PARallel Self-consistent E-cloud Code) for ultimate full 3-D self-consistent beam-

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cloud simulations.

Existing and currently used codes both for electron cloud build up and instability studies are mostly non-parallel and make use of analytical or PIC field solvers. Tracking codes, in which an electron cloud module should be integrated, are parallel and can handle up to 3 dimensions. (WARP, ORBIT). PARSEC will be able to describe a well defined accelerator section with full tracking both for the beam particles (which are transported at each turn through the real lattice of the ring) and for electrons. Inside the window of interest, electrons and bunch particles will be treated self-consistently in 3-D using finite element discretisation on a scalable parallel multigrid. A. Adelmann showed that the computing time scales linearly with the number of processors for a set of 2-D Poisson solver algorithms and underlined the need of powerful supercomputers to make large steps in science.

On the benchmark side, he proposed a-posteriori a comparison of the different e-cloud codes against the two-stream instability, and a code-to-code comparison based on short (NLC damping wigglers and SPS/LHC) and long bunches (PSR). The instability of the long PSR bunch could also be used as benchmark case for the instability codes.

Can the electron cloud harm the performance of NLC and TESLA?

M. Pivi presented a detailed study on how the electron cloud can threaten the safe operation of the NLC and TESLA daming rings. Build up simulations were done for damping wigglers, arcs, and long straight sections. The threshold for the electron cloud instability onset was then investigated by using and comparing different codes.

All the build up simulations presented by M. Pivi were done with the POSINST code, and a review of its pre-existing and ad hoc added features was given in the introduction. In the wigglers, maximum SEY's of about 1.3 are found to be sufficient to drive electron cloud formation up to densities of 10^{12}–10^{13} m^{-3}. The threshold is about the same in the arcs, but increases to 1.4–1.5 if an antechamber is included in the simulation. Electron trapping occurs in quadrupoles, causing the existence of long-lived electrons. The threshold in field-free regions is about 1.5 for NLC, and even higher for TESLA. In the positron transport lines the electron cloud is only expeccted to be an issue for the normal conducting colliders (NLC), where the bunches are closely spaced (1.4 ns), but not for TESLA, where the large bunch spacing (337 ns) is a natural protection against electron multipacting.

Instability simulations carried out with the HEADTAIL code, and cross-checked with Ohmi's code PEHTS and with QuickPIC from USC-UCLA, show a threshold for electron cloud instability at around 10^{12} m^{-3} for NLC (corresponding to a maximum SEY of about 1.6) and a much lower threshold for TESLA (about 10^{11} m^{-3}). The very low threshold value found for TESLA is still under investigation because the emittance growth occurring for so low electron cloud densities might be caused by some numerical still unexplored effect.

A number of possible countermeasures can be adopted in order to avoid the cloud formation. For example, conditioning can help reduce the SEY below the threshold values. Also grooved surfaces can bring the SEY values further down by another 35%.

Electron cloud in the TESLA and CLIC positron damping rings and in PETRA III

R. Wanzenberg presented in this session his work on simulations of electron cloud build up in the light source PETRA III and in the TESLA and CLIC damping rings.

All simulations presented by R. Wanzenberg were done with the ECLOUD code. In spite of the different bunch spacings (96 and 4 ns, respectively), PETRA II (existing) and III (foreseen upgrade) are both expected to suffer from an electron cloud if the maximum SEY is assumed to be 2.2. The wake field of the electron cloud is nevertheless well below the threshold for strong head-tail coupling.

The straight sections of the TESLA damping rings can be affected by electron cloud if the SEY is above 1.6, which agrees well with what M. Pivi calculated based on POSINST simulations. A very dense electron cloud is then foreseen to build up both in the straight sections and in the arcs of the CLIC damping rings. Countermeasures are necessary to avoid that, because the tune shift associated with the simulated cloud densities would make it impossible for the CLIC damping rings to work.

Is there an electron cloud in DAΦNE? Observations vs. simulations

DAΦNE has always been one of the great puzzles in the electron cloud studies, since, in spite of the range of parameters in which it operates, there was never any direct or indirect observation of electron cloud in it. C. Vaccarezza summarized some "contradictory" observations in DAΦNE, which could either be explained with the presence of an electron cloud in the ring or on the contrary rule it out. She also showed simulations (carried out with the ECLOUD code), which prove that an electron cloud would be expected in most of DAΦNE sections.

The observation of an instability with relatively low threshold arising in the positron ring when the electron ring is not filled, could be explained with a dense electron cloud in the interaction region which gets cleared up when electrons are also circulating. This idea is also supported by the observation that the threshold is higher when the longer solenoid of FINUDA is on than when the solenoid of KLOE is on. No sensible conclusion can be drawn from the beam transverse size measurements as a function of the positron beam intensity. First of all, there is no clear increasing trend in x nor in y over the swept range of intensities, and beside that, the measurements are averaged over one bunch train and we cannot infer the $\sigma_{x,y}$ variation along the bunch train (which would be an evident fingerprint of electron cloud). Tune shift measurements as function of the beam intensity show an interesting difference between electrons and positrons. The asymmetry between x and y in the positron ring can be explained with a positive current dependent tune shift present only in the positron ring in addition to the regular tune shift induced by the ring impedance. This would be generated by an additional constant focusing term present only in the positron ring. Pressure measurements do not support the presence of an electron cloud. No strong pressure increase was ever recorded at any time, whereas we would expect that with an electron cloud in the positron ring, the pressure in it would rise due to electron induced desorption along the ring.

C. Vaccarezza showed electron cloud build up simulations done for the arcs, the splitter dipoles and the drift spaces. She evaluated the correct photoelectron bombardment for each of these sections and scanned different values of the photoelectron reflectivity. Confirming preliminary results from other studies done over the last few years, the electron cloud would be expected to build up in most of these regions independently of the photoelectron yield and the wall reflectivity.

Merging POSINST and WARP

J. L. Vay reported on the status of the merge between the electron code POSINST and the tracking code WARP.

The main motivation for the merge lies in that each of the codes can separately treat specific problems in great detail, but to fully describe both the beam transporrt and its coupling with the environment, they complement each other and each one needs the other's tools for self-consistency. The complete model of the merged POSINST-WARP is organized as follows. All the SEY routines have been extracted from POSINST and packaged by Tech-X in the library CMEE. Besides, POSINST provides the input deck, the main control loop, the electrons, the beam kick, the particle mover and part of the diagnostics. WARP provides the field-solvers and the diagnostics. Presently POSINST and WARP can be started at the same time using Python, particle data are unified (for example, the arrays with the beam particle coordinates from the two codes point actually to the same memory locations), and POSINST can be directly run from the WARP graphical interface and data can be plotted like WARP produced data. In the future it is planned to pass the main control loop and the particle mover to WARP, and to also make use of the full lattice description avialable through WARP.

The ultimate goal of this work is to predict and optimize machine performance and design future machines based on multiparticle simulations from the very start.

Electron cloud simulations in ISIS, ESS, PSR

G. Bellodi presented results of electron cloud build up simulations in the ISIS synchrotron, using a version of the ECLOUD code adapted for the treatment of intense non-relativistic long bunch proton machines.

For field free regions, a comparative study between ISIS, PSR and ESS showed that:

- With parabolic bunch profiles, the electron cloud build up is stronger in PSR and ESS than in ISIS;
- The build up pattern looks similar in ESS and PSR, but different in ISIS because of its high proton losses and large bunch spacing;
- There is a significantt sensitivity of the results to bunch intensity and profile, and to the model adopted for the secondaries. In particular, critical parameters seem to be the elastic electron reflection at low energies and the relative population of the three components of electrons coming from electron on wall impacts (reflected, rediffused and true secondaries) together with their specific energy distributions;
- Simulation results from ECLOUD remarkably converge with those from POSINST when the same model for the secondaries is used, thus providing a good example of successful benchmark between these two build up codes.

A few simulations in dipole chambers were shown and results do not much differ qualitatively from those discussed above. Finally, to compare this simulation study with machine experiments at ISIS, a deeper understanding of the role of the RF shields in the vacuum chamber and surface measurements on the secondary emission properties of the ceramic walls would be of critical importance.

Some general remarks

Sam Heifets' concluding remarks pointed to:

- The necessity to develop self-consistent build up and instability simulations. S. Heifets showed with an example from the fast ion instability, that the dynamics of the build up is strongly affected by whether one considers a rigid bunch or a bunch that interacts with the cloud that is building around it. The interplay seems an indespensable ingredient in coasting beam simulations, but for a bunched beam, due to the discontinuous build up process, the approximation so far used to separate the two processes of build up and instability might in fact still hold.
- The influence of the beam field and of the ions in the beam pipe on the yield. A simple calculation shows that the beam field and the ions (if any) could lower the secondary emission yield and therefore should also be accounted for in a complete modeling of the electron cloud questions.

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